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Full Length Research Paper

Development of the sugarcane harvester using a small engine in Northeast Thailand

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This research presents the developing sugarcane harvester using small engine in order to focus on its appropriateness in sugarcane farming for farmers who are encountering problems of labor shortage and sugar factories lacking sugar cane for producing sugar. It is operated by 180 hp (134.28 kW) at 2500 rpm. Sugarcane was harvested at 12 months after planting with an average-stalk length of 1.8 m, and average-stalk diameter of 0.0254 m; each clump consisted of 8 to 12 stalks, the distance of each sugarcane row was 1.20 m. The sugarcane harvester using small engine can perform at an average speed of 1109.73 m^2/h with fuel consumption of 20.03 l/h and at a mobile speed of 0.25 km/h. The percentage of sugarcane-cut stalks is 100% since this engine is installed with double blades with a speed of 1,090.5 rpm; a speed of leaf-cutting blades is at 669 rpm with the break even point of 122,572.8 kg/year and the payback period of 2 years.

Key words: Sugarcane, harvester, small engine.

INTRODUCTION

Sugarcane is one of the major economic crops in Thailand. It is used as a raw material in sugar manufacturing. Recently, Thailand is the second-biggest sugar exporter after Brazil. At present, Thailand has cultivating area of 8.46 million raise (1.36 million ha) producing sugarcane stem of 95.44 million tons (Office of the Sugarcane and Sugar Commission, 2011). Furthermore, in Northeastern Thailand sugarcane is one of the most important crops. Generally, farmer groups are a small-farming group (0.16 to 8.9 ha). Thai agriculture of Thailand relies heavily on human labor which results in low productivity per area of per labor so it wastes a lot of time on working process. Human labor shortage tends to be a serious problem and rapid agricultural industrial development. Result in development of the agricultural machinery used to harvest.

In a previous work, Pilcher (1983) investigated design and development of a simple chopper harvester. Magalhães and Cerri (2007) studied a yield monitor sensor of harvester for the sugarcane yield. Yadav et al. (2002) studied the performance evaluation of sugarcane chopper harvester mechanical harvesting. Most of the previous studies applied large-scale imported harvesters and the current price is very expensive ($500,000) when compared with the small-scale harvester developed in this research ($32,446). In addition, the large-scale imported havesters are designed for large-scale farming areas, which require 1.50 m of the distance of each sugarcane row. Some of the small-scale Thai farming areas employed the sugarcane row distance of 1.2 m. Therefore, it is not possible for the large-scale harvester to drive through the row. Thus, the current research and development aimed at solving these problems by designing and constructing a sugarcane harvester using small engine. This design would benefit the small-scale farmers of Northeast Thailand.

MATERIALS AND METHODS

Design specifications of harvester

A harvester is designed for a small-farming group and the labor shortage tends to be a serious problem when the cost of harvester

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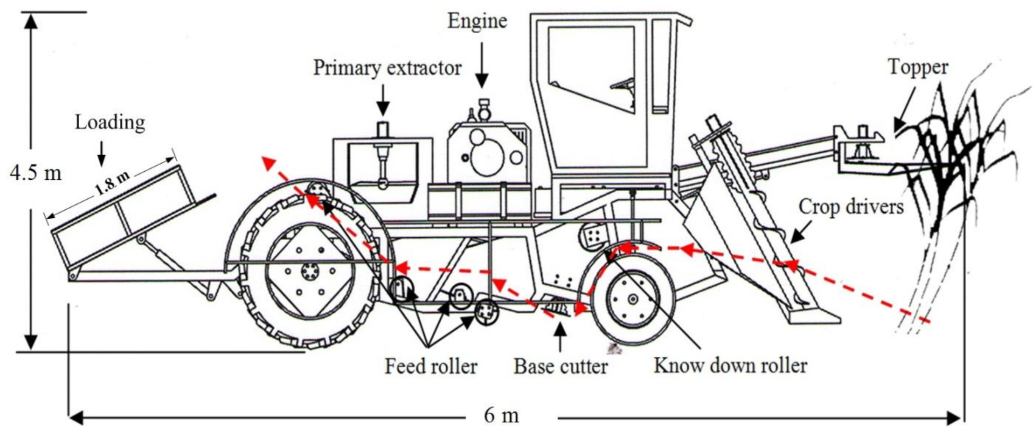

Figure 1. The component of the sugarcane harvester.

less than 1 million baht ($32,466.48) the operation principle of the harvester is simple. Figure 1 shows the side view of the designed harvester. The system was designed with the following specification.

Frame fabrication

A beam is a major structural design meant to support loadings perpendicular to longitudinal axes, under load, internal shear force and bending moment that vary along axis of beam. The load-beam structure consists of driver weight of 80 kg, cane of 550 kg and harvester of 2,800 kg. The beam is designed to resist shear and bending moment is designed on the basis of strength, as follow:

i) Draw shear and moment diagrams, as shown in Figure 2,

ii) Determine the modulus of beam section (S),

iii) The section modulus of the selected beam must be equal to or greater than the section modulus required at allowable stress $(S_{select} \geq S)$,

iv) Verify that in the bending (Δ) resistance of beams from the selected.

The modulus of the beam section can be calculated by equation:

$$S = \frac{M}{f_b} \tag{1}$$

Equation 1 will be substituted by Equations 2 and 3

$$M = 1/8 \times WL \tag{2}$$

and

$$f_b = \frac{My}{I} \tag{3}$$

where M is maximum bending moment (N·m), W is total load (N), L is length span (m), y is distance from neutral axis (m), *I* is moment of inertia (m^4) and f_b is bending stress from dynamic load (N/m^2). The dynamic analysis of the structure is an essential procedure to design a reliable structure subjected to dynamic loads while the harvester is moving. The dynamic loads considered in this work include a driver weight of 80 kg, a sugarcane weight of 550 kg and a harvester weight of 2,800 kg.

Based on the dynamic loads, the calculated bending stress (f_b) was 89.29 MN/m^2. Since the structure material in this work is St-37, its bending stress in dynamic loading allowance ($f_{b,allowance}$) is 100 MN/m^2, according to bending stress allowance table (Frank, 1962). Thus, the bending stress in this design is less than the dynamic loading allowance, thus the structure could resist damages from dynamic loading.
The bending resistance check by ensuring Equation 4 is satisfied:

$$\Delta = \frac{WL^3}{48EI} \tag{4}$$

where *E* is modulus of elasticity (N·m).

Crop drivers and feeding

Crop drivers are designed at 45° to separate the cane row being harvested from adjacent rows. It consists of two contra-rotating spirals which separate the rows. Vine knives prohibit cane and weeds from entangling the drivers. It rotates at approximately 60 rpm**.** Feed roller was used to feed the cane uniformly into the chopper system and cleaning also occurs through gaps, between feed rollers and choppers, as the cane passes through the rollers. These gaps allow dirt to fall from the cane before chopping. It rotates at approximately 60 rpm. Knock-down roller is tubular roller of feeding system used for controlling the inclination angle of the cane stalks forward to an angle of 45° with fixed front of base cutter.

Base cutter and topper

A base cutter is used to remove the tops from the cane stalk and spread the tops evenly on the ground. It includes 4 (2 sets) blades on a rotatable shaft with diameter of 0.5 m, and a thrower having a

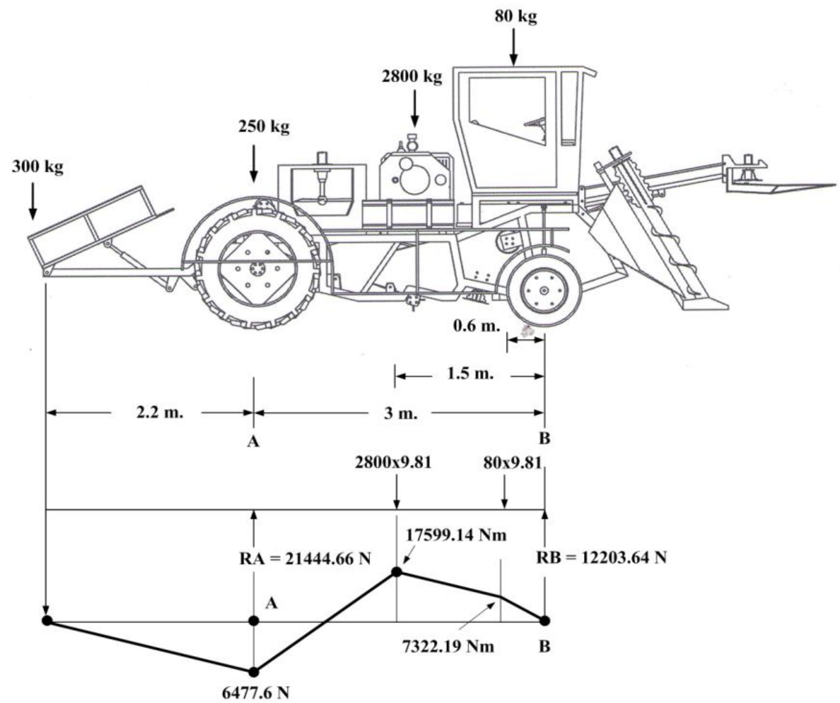

Figure 2. Shear and moment diagrams of beams.

vane extending from a thrower shaft, the two shafts being paralleled and counter-rotated which can be tilted to cutting the cane stalk. The topper was used to remove the tops from the cane stalk and spread the tops evenly on the ground. It includes 4 blades on a rotatable shaft with a diameter of 0.5 m.

Loading and primary extractor

Loading is installed at the back of the harvester with a size of 1.2 m wide × 1.8 m long × 0.5 m high in order to load the average harvested sugarcane length of 1.8 m. Capable of containing 550 kg of sugarcane, the primary extractor was designed with an aim to clean billets and remove the remaining dirt and resulting in cleaner cane.

Wheel drive, steering and lifting system

A harvester has two-wheel drive and rear wheel which are based on a variable-displacement pump supplying fluid directly to a fixed-displacement motor. The steering is used for controlling the left-right movement of the harvester, works with hydraulic system and loading systems used for controlling the level of the base cutter.

Engine and hydraulics system

The engine power is transmitted by hydraulic system to the devices. For the selected engine, it is determined by the size of the required power for all devices. The power engine of harvester was tested for 180 hp (134.28 kW) at 2500 rpm. The power engine can be calculated by:

$$Power = 0.00167 \times P \times Q \tag{5}$$

where P is hydraulic pressure (kg/m^2).

Typically, the commercially available diesel small engine products for harvester with operating pressure of 140 bar (1.4x10^4 kg/m^2) and Q is oil flow rate at hydraulic cylinder (l/min) and is defined as:

$$Q = VA \tag{6}$$

where *V* is velocity of flow of hydraulic oil in m/s and *A* is cross-sectional area of cylinder (m^2), and is found by the equation:

$$A = \frac{F}{P} \tag{7}$$

and

$$A = \frac{\pi D^2}{4} \tag{8}$$

where F is fluid force (kg·m/s²) and *D* is inner diameter of hydraulic cylinder (m).

Figure 3, 4 and Table 1 show the sugarcane harvester using a small engine and specification of the harvester.

Experimental harvester

This research is aimed at studying the sugarcane harvester using small engine with its width of 1.6 m, its length of 6 m, its stalk-cutting blade which has a diameter of 0.5 m and its engine of 180 hp (134.28 kW) at 2500 rpm. Sugarcane having a harvesting period of 12 months was used as a sample, Kosum Phisai, Mahasarakham province, Thailand with the average-stalk height of 1.8 m, and the average-stalk diameter of 0.0254 m (1 inch); each clump consisted

Figure 3. Sugarcane harvester.

Figure 4. Operation of the sugarcane harvester using small engine.

of 8 to 12 stalks, the distance of each sugarcane row was 1.20 m. The harvesting performance was evaluated in a field 45 × 200 m in size with a rectangular shape.

For experimental testing, the performance of harvester consists of the efficiency of sugarcane-cutting, based on 60 minus of harvester operation. The criteria were the testing area on the efficiency of sugarcane cutting, the amount of fuel consumption, the percentage of cut stalks, the speed of movement calculated from the distance of the sugarcane cutting per time, the rotation speed of stalk-cutting and leaf-cutting blades measured by a proximity sensor.

The area of sugarcane cutting is calculated by the following equation:

$$\text{Area of sugarcane cutting } (m^2/h) = (W_{dis} \times V_{speed} \times 1{,}000)/1{,}200 \quad (9)$$

where W_{dis} is the distance of each sugarcane row (m) and V_{speed} is speed of sugarcane harvester (m/h). Percent of sugarcane cut stalk was calculated by:

$$\text{Sugarcane cut stalk } (\%) = (A1/A2) \times 100 \quad (10)$$

where A1 is yield of the sugarcane cut stalk (kg) and A2 is yield of the sugarcane stalk in the patch of sugarcane (kg). Percent of breakage sugarcane cutting blade was calculated by:

$$\text{Percent of breakage sugarcane cutting blade } (\%) = (C1/C2) \times 100 \quad (11)$$

where C1 is yield of breakage sugarcane from cutting blade (kg) and C2 is yield of sugarcane from cutting blade (kg).

Table 1. Specification of the harvester.

Item	Details
Diesel engine	180 hp (134.28 kW), @2500 rpm
Total length	6 m
Total width	1.6 m
Height	4.5 m
Width of rear wheel	2 m
Wheel base	1.2 m
Net weight	1,200 kg

RESULTS AND DISCUSSION

Sugarcane was harvested at the 12th month after planting with an average-stalk high of 1.8 m, and average-stalk diameter of 0.0254 m; each clump consisted of 8 to 12 stalks; and the distance of each sugarcane row was 1.20 m. It was shown that, the performance of the engine which is shown according to Table 2, also reveals that this engine can perform its cutting efficiency at an average speed of 1109.73 m^2/h. During harvesting the forward speed of sugarcane harvester was observed as 0.25 km/h with the fuel consumption of 20.03 l/h. The area of sugarcane cutting was 1109.73 m^2/h. The percentage of sugarcane-cut stalks is 100% since the engine is installed with double blade so that all stalk is smoothly cut. A rotation speed of stalk-cutting blade is at a 1,090.5 rpm, a rotation speed of a leaf-cutting blade is at a 669 rpm and Table 3 shows the summary of harvester performances.

The field test of harvester which is the cutting quality for stalks was satisfactory for a smooth cutting surface quality. There was found no fracture of vascular tissues, filaments in cutting locality, and cutting surface that was not clean and smooth as shown in Figures 5 and 6. It has shown a height from the ground of each cut stump, a smooth trace of each stump and a sprout of each stump after it was cut by the cutting blade, as shown in Figure 7.

ECONOMIC EVALUATION

The development of the sugarcane harvester used a small engine. The economic analysis is necessary for the suitability in an investment. It consists of the break-even point (BEP) and payback period. There was shown the break-even point of using harvester of 111,725.7 kg/y

Table 2. Performance testing results of sugarcane cutting of the harvester using small engine.

Time (min)	Area of sugarcane cutting (m^2)	Fuel (litre)	Speed of movement (km/h)	Percent of breakage sugarcane cutting blade (%)	Speed of sugarcane stalk cutting blade (rpm)	Speed of sugarcane leaf cutting blade rpm)
10	190.00	6.30	0.24	0.00	1160.00	712.00
20	400.00	7.80	0.24	0.00	1137.00	695.00
30	608.00	8.90	0.24	1.00	1112.00	687.00
40	720.00	9.60	0.25	0.00	1078.00	656.00
50	832.00	11.30	0.25	2.00	1034.00	643.00
60	1,024.00	13.20	0.25	0.00	1022.00	621.00
Average	1109.73	20.03	0.25	0.50	1,090.50	669

Table 3. Summary of the harvester performances.

List	Results
Area of sugarcane cutting (m^2/h)	1109.73
Fuel consumption (l/h)	20.03
Mobile speed of movement (km/h)	0.25
Percent of breakage sugarcane cutting blade (%)	0.50
Percent of sugarcane cut stalk (%)	100

Figure 5. A smooth trace of each cut stump from cutting blade.

Figure 6. A height from the ground of each cut stump.

Figure 7. A sprout of each cut stump after cutting blade.

Table 4. The economic evaluation of the harvester.

Item	Values
Harvester costs	$32,466.4
Fixed costs	3,366.67 $/y
Selling price per unit	$0.03
Variable cost	$0.0052
Annual cash revenues	$25,280
Breakeven point	122,572.8 kg/y
Payback period	2 years

Table 5. Comparison of the performance and economic evaluation.

List	Sugarcane harvester small engine	Imported sugarcane harvester
Engine (hp)	180	350
Fuel consumption (l/h)	20.3	45
Average speed (m^2/h)	629	3000
Price (USD)	32,466.48	500,000
Payback period (years)	2	6

and payback period of 2 years. The results of an economic evaluation of using the sugarcane harvester using a small engine are reflected in Table 4. In this research, the value of calculation was used for the analysis with the following.

1. The harvester capacity was 5,000 kg/h.
2. Fuel consumption was 20.03 litre/hr (the fuel cost was 1.3 $ /L).
3. The harvester with operating time 8 h/day and 4 months/year.
4. Rate of interest was 2%.
5. Maintenance costs was 1.67 $/h.
6. Maximum lifetime of 10 years.

The breakeven point can be calculated by:

$$BEP = TFC/ (P_{sell}-V_{cost}) \tag{12}$$

where TFC is fixed costs, ($/y), V_{cost} is variable cost, $/kg) and P_{sell} is selling price per unit weight, ($/kg).
The Payback period can be calculated by:

$$\text{Payback period} = \text{Cost of project Annual cash revenues} \tag{13}$$

Table 5 compares the performance and economic evaluation between the small-scale harvester (180 hp) in this study and a typical imported large-scale harvester (350 hp). It was found that the fuel consumption of the small engine was approximately half of that of the imported one. Although the average speed of the harvester using small engine is lower than that of the imported one, the price of the currently developed harvester is much lower than the imported one. Specifically, according to the economic evaluation, the price of the current design is $32,466.48 compared to $500,000 for the imported one. Therefore, the current development is beneficial for farmers of lower capital investment. In addition, the small harvester has an advantage over the imported one as the payback period of the former is only 2 years compared to 6 years of the latter.

Conclusion

Development of sugarcane harvester using small engine in order to be suitable for farmers in sugarcane farming in northeast Thailand revealed that this engine can perform its cutting efficiency at an average speed of 1109.73 m^2/h with fuel consumption of 20.03 l/h and at a mobile speed of 0.25 km/h. The percentage of sugarcane-cut stalks is 100%; since it is installed with double blades, all stalks are smoothly cut. A rotation speed of a stalk-cutting blade is at 1,090.5 rpm, a rotation speed of a leaf-cutting blade is at 669 rpm. The economic evaluation represents the break even point of using harvester of 122,572.8 kg/y and payback period of 2 years.

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Nomenclature

A: Cross-sectional area of cylinder (m^2).
BEP: Break even point.
D : Inner diameter of hydraulic cylinder (m).
E : Modulus of elasticity (N·m).
f_b **:** Bending stress from load and resistance factor design (N/m^2).
F : Fluid force (kg m/s^2).
I: Moment of inertia (m^4).
L **:** Length span (m).
M **:** Maximum bending moment (N·m).
P: Hydraulic pressure (kg/m^2).
P_{sell}: Selling price per unit ($/kg).
Q : Flow rate at hydraulic cylinder (l/min).
S **:** Section modulus (m^3).
S_{select} **:** Section modulus required at allowable stress (m^3).
TFC: Fixed costs (kg/y).
V_{cost} Variable cost ($/kg).
V : Velocity of flow of hydraulic oil (m/s).
V_{speed}: Speed of sugarcane harvester (m/h).
W **:** Total load (N).
W_{dis}: Distance of each sugar cane row (m).
y **:** Distance from neutral axis (m).
Δ **:** Bending resistance (m).

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